that the timescale is correct[7]. But it indicates a close agreement in the phase relationship between the series, and thus in the underlying frequencies.

From the optimal fit between their record and the astronomical index ($La90_{(1,0.5)}$), Lourens and colleagues conclude that the combined effects of dynamical ellipticity and tidal dissipation have, on average, been smaller over the past three million years than they are today. From this 'best fitting' astronomical solution, they can also determine the rate of change in the length of the day. Moreover, as dynamical ellipticity and tidal dissipation are parameters in the computation of obliquity and precession, the changes in these periods can also be estimated for the same time interval.

Although these new results[1] aren't necessarily in direct conflict with those of Pälike and Shackleton[6], we obviously need a more precise picture of past variations in Earth's orbital parameters. First, Lourens and colleagues' results will have to be confirmed by similar studies of other climate records (which, at the same time, should reduce the uncertainty estimates on the results). Second, some assumptions, related for example to the lag between precession and obliquity and to the robustness of the control point, should be tested and justified. Third, the same analysis should be applied to a longer interval of time. Attempts[8] to calibrate the proxy record much further back in time, for instance in the Early Mesozoic around 200 million years ago, are giving promising results. Such attempts are mainly based on matching the proxy record to the variations in eccentricity, because eccentricity is much more stable through time than the other orbital parameters.

What of the future? Geological climate records are becoming available for longer periods of time. Different techniques are being used to help estimate the best fit between astronomical theory and geological records. And astronomical computations are continually being extended and improved. All in all, these complementary approaches mean bright prospects for improving understanding of both Earth's climate in the remote past and how the climate record can inform celestial mechanics. ■

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Ecology

Bagging the lag

Michael E. Hochberg and Arthur E. Weis

New techniques for analysing the dynamics of moth populations in captivity could have broad implications for biodiversity and conservation research in general.

Predicting changes in the size of natural populations has long been a goal of ecologists. But it is often far from simple to unravel the dynamics of populations. We rarely know all of the factors that affect them, let alone the many ways in which individual populations interact. Hence the importance of the paper on page 1001 of this issue[1], in which Bjørnstad and co-workers — using data collected from plastic boxes stocked with meal moths and their natural enemies — evaluate new ways of analysing population dynamics.

Theory predicts that populations are more likely to persist if their size is kept in check. In other words, there is a maximum number of individuals per population that can survive in a given environment. But it is difficult to detect such 'density dependence' and to estimate the extent to which it contributes to population stability[2,3]. One problem facing ecologists is that many environmental factors impinge on population sizes, affecting density to different degrees. Such factors include abiotic variables, such as rainfall and temperature, and biotic influences, such as resources, competitors and natural enemies.

Is there any hope of disentangling the effects of this multitude of variables? If so, it would seem reasonable to start with long-term data collected from simple environments with only a few interacting species. Recent research[4] indicates that data collected from natural populations can carry the characteristic imprints of an interaction (or 'coupling') between two populations. Bjørnstad *et al.*[1] go a step further, by showing how a different type of population signature — the lag between the introduction of a parasite and its effect on the density of a host population — may be associated with the coupling of the dynamics of the host and parasite populations.

Bjørnstad *et al.*'s data come from their previous laboratory study[5] of the moth *Plodia interpunctella*, a pest that feeds on stored products such as flour, nuts and dried fruit. Moths were cultured alone or with either the parasitoid wasp *Venturia canescens* (which lays its eggs in *P. interpunctella* larvae) or the *P. interpunctella* granulosis virus. In the absence of wasps or viruses, moth populations showed peaks in abundance with a period of one generation (so-called generation cycles). The viruses had little apparent effect when confined with the moths, but the wasps did, deepening the cycles' troughs. This broad difference formed the basis for Bjørnstad *et al.*'s present study[1].

When the dynamics of a population are dependent on its density, its size at one point in time may be influenced by its size and composition in the recent past. For instance, older *P. interpunctella* larvae eat younger ones, so low numbers of mature moths at one time may reflect the lagged effect of an earlier abundance of cannibals. Other interactions — including density-dependent parasitism — can cause further lags. Lags can be detected by determining whether the current population size can be predicted by its size at various times in the past. For example, when cultured alone, *P. interpunctella* larvae show three density-dependent population lags; the first of these reflects the state of the population a week previously, when the population density was dependent on competition for resources and the cannibalism of small larvae by large ones. Bjørnstad *et al.* refer to the number of lags as the 'dynamical dimension' (three, in this case).

Bjørnstad *et al.* dissect moth population dynamics with surgical precision. First, using a time-series method, they find that adding the virus to the moth population does not change the dynamical dimension, whereas adding the wasp parasite increases it by two lag terms. Second, the authors show that the number of adult moths decreases with past wasp abundance, but is not adversely affected by the past number of moth larvae that were infected with the virus. By untangling the dynamical dimensionality in each case, Bjørnstad *et al.* show that the moth and wasp populations, but not the moth and virus populations, are tightly coupled.

Next, to see more clearly the inner workings of the dynamical dimensions, the authors construct a simple population model, and use it to identify the processes that contribute to each lag. Interestingly, the parasitoid wasp not only increases the number of lags, but also qualitatively changes the lags. These changes, although complex, involve the addition of new terms reflecting trophic (feeding) interactions, and the modification of existing terms. Finally, Bjørnstad *et al.* apply a statistical method to their raw data, and confirm the findings based on the time-series method and the population model.

We do not yet know how useful Bjørnstad *et al.*'s methods will be in identifying the important variables in other systems, including natural ones. Theory predicts[6] how the dynamics of a population will be affected by the strength of coupling between two species. But it is not yet clear whether coupling to more and more variables inexorably increases the number of lags.

However, on the empirical front, thousands of sets of population data exist[7]. Although it would take a herculean effort to analyse them all, breakthroughs may be in the offing. The same group previously showed[8] that by increasing the depth of *P. interpunctella*'s artificial diet, the wasps' attack rate could be diminished, resulting in a weaker effect on the moth's population dynamics. Combining this system with the new analysis techniques will provide an opportunity to test whether varying a habitat parameter affects the strength of coupling of the system. The prediction here is that coupling between moth and wasp population dynamics should decrease as diet depth increases.

There are also broader implications. The group previously found[5] that when both virus and wasp confront the moth together, the simple generation cycles found in the one- and two-species systems are thrown out of whack: the three-species system exhibits transient cycles of longer periods, and eventually becomes extinct. If the imprints of one or both enemies on these cycles could be found, we would be a step closer to knowing whether Bjørnstad *et al.*'s techniques can be applied to biodiversity and conservation research, where one might want to know how a species that is harmless in one context can lead to the collapse of part of a community in another. These techniques could also be used to show how the use of two natural enemies as biological pest controls yields outcomes that are qualitatively different to the outcomes of using either enemy alone[9]. ■

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Turbulence

Go with the flow

Itamar Procaccia

Traditional devices for measuring turbulence have been unable to keep up with the latest developments in theory. But detectors derived from high-energy physics may narrow the gap between experiment and theory.

Turbulence is the chaotic and unpredictable motion of fluids flowing at high rates. It plays a major role in many processes from the environmental, for example cloud formation, to the technological, such as in industrial chemical reactors. Clearly, a deeper understanding of this phenomenon would be beneficial, and in recent years much progress has been made in the fundamental theory underlying turbulence. But the ability to measure turbulence experimentally has not advanced at the same rate, making it difficult to verify the theoretical developments.

On page 1017 of this issue, Eberhard Bodenschatz and collaborators[1] report an important technical improvement to the way in which turbulence is measured. This advance may make a decisive contribution to bringing experimental turbulence research back on par with theory.

In their experiment, Bodenschatz and co-workers[1] modified a detector from Cornell's electron–positron collider. They used 'silicon strip' detectors to optically image tracer particles (tiny transparent beads) in turbulent water flow. Compared with previously available techniques, this method offers unprecedented time resolution of up to 70,000 frames per second. As a result, the researchers were able to measure the acceleration of the particles in turbulent water, discovering that it can reach 1,500 times the acceleration of gravity. The high time-resolution of the measurements indicates that the acceleration is highly intermittent, reflecting the complex structure of turbulent flow.

At present, the standard probe for turbu-

100 YEARS AGO

A simple workable, absolutely trustworthy system is still urgently wanted for the detection of criminals, and if the authoress of this book has succeeded she certainly deserves the thanks of all the Governments of Europe… It so happened that about seven years ago the reviewer came to the conclusion that the external ear ought to yield some clue to the relationship of man and ape, and of one race of man to another… To test the "criminal-mark" theory of Lombroso and many others, he examined the ears of more than 800 confirmed criminals, and of more than two thousand inmates of asylums for the insane, situated in parts of the country where he had already examined the ears of the sane. Altogether the ears of more than 40,000 people of different races and of different moralities, besides those of about 300 apes and anthropoids, were examined, but the total results of this elaborate investigation were almost entirely of a negative nature… If the reviewer's methods and observations are correct, the confirmed criminal's ear is the ear of the average inhabitant of Great Britain. Nor did the ears of the insane differ, on an average, from those of the people from which they were drawn, and if the authoress had carried her observations over a number of men of genius or of high ability, instead of drawing elaborate deductions from single observations, she would probably have arrived at a similar conclusion as to them.
From *Nature* 21 February 1901.

50 YEARS AGO

Miss Dorothea M. A. Bate, who died after a brief illness on January 13 at the age of seventy-two, was for more than fifty years one of the outstanding personalities at the British Museum (Natural History). When only seventeen, and with neither qualification nor encouragement, she started work in the Bird Room as a voluntary worker; but her interests lay chiefly in palaeontology in relation to the Recent fauna, rather than in the Recent fauna itself… During 1901–1902 Miss Bate explored the caves of Cyprus and made some notable discoveries, such as the remains of pigmy elephants, and soon extended her interest to cave deposits in Crete, the Balearic—where she discovered the unique 'antelope' *Myotragus*—Malta and Sardinia, working meticulously and earnestly and always alone.
From *Nature* 24 February 1951.